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FIRST COMPARISONS OF CONTEMPORARY SCARAB AND CERES RADIANCES

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1. INTRODUCTION

Broadband Earth radiation budget (ERB) components have been monitored from space since the late 1970's through successive independent missions. To construct a consistent long-term data set of ERB observations requires stable and reliable calibration sources as well as periods of overlap between successive missions so that the instruments can be inter-calibrated.

Narrow-field-of-view (NFOV) scanning radiometer measurements were carried out by the Earth Radiation Budget Experiment (ERBE) from 1984 to 1989 and are currently being performed by the Clouds and the Earth's Radiant Energy System (CERES) and Scanner for Radiation Budget (ScaRaB). These ERB instruments measure broadband radiances using a solar spectral channel (shortwave or SW: 0.2-4.0μm) and total channel (0.2-100μm). The terrestrial radiation (longwave or LW: 4.0-100μm) is derived from the total channel at night and from the difference between total and SW radiances for daytime measurements.

While ERBE NFOV instruments ceased to operate in 1989, ERBE wide-field-of-view (WFOV) non-scanning radiometers are still in operation in 1999. Green et. al. (1990) have shown that the WFOV and NFOV instruments agree to within 1% for LW and 2.5% for SW. The first ScaRaB flight model flew on the Meteor 07-3 platform and collected data from March 1994 through March 1995 (Kandel et al., 1998). Bess et al. (1997) applied the method derived by Green et al. (1990) to compare ScaRaB NFOV and ERBE WFOV data for March 1994 and found differences on the order of 1% for SW and nighttime LW and 4% for daytime LW.

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The CERES protoflight model (PFM) has been gathering ERB data on the Tropical Rainfall Measuring Mission (TRMM) platform since January 1998 (Wielicki et al., 1996). It provided partial coverage of the 1997-1998 El Niño/Southern Oscillations event. Due to a failing voltage regulator, the CERES instrument stopped routine gathering of science data in September 1998. Continuous data collection will resume in August 1999, soon after the launch of CERES FM1 and FM2 onboard the Terra platform (formerly EOS-AM). This will allow inter-calibration between CERES PFM and FM1/FM2 instruments in order to tie the most recent data record to the earlier time series.

The second ScaRaB flight model (FM2) was launched on July 10, 1998 on-board the sun-synchronous Resurs-01/4 satellite (10am descending node). It is currently the only NFOV ERB instrument providing global spatial and temporal coverage of the Earth, monitoring the current La Niña tropical anomaly. If the broadband ERB components of the 1998 El Niño and the 1999 La Niña events are to be compared, accurate inter-calibration between CERES PFM and ScaRaB FM2 sensors must be established. This is also the first opportunity in nearly 10 years to perform comparisons between contemporary broadband scanner ERB data sets observed from separate space platforms and it is the first opportunity to compare directly ERBE/CERES type scanning radiometers to ScaRaB radiometers.

2. RADIANCE MATCHING TECHNIQUE

Radiances measured from the CERES and ScaRaB sensors are sensitive to viewing and illumination geometries (viewing zenith angle for LW and SW and solar zenith and relative azimuth angles for SW) as well as spatial and temporal heterogeneities of the radiative fields used in the comparisons.

2.1 ***Matched Viewing Geometry***

At each orbital crossing thousands of overlapping CERES and ScaRaB footprints can be found but only about one hundred of them have matched viewing zenith angles and only close-to-nadir footprints are free of azimuth-angle dependence. Angular dependence models can be used to compare all footprints but could introduce significant errors in the comparison. The rotating azimuth capability of the CERES instrument is used to align its scanning plane to the cross-track scanning plane of ScaRaB for crossings occurring in daylight. Each crossing can yield up to 51 and 102 matched SW and LW radiances, respectively. The alignment angle is determined for orbit crossings within 15 deg of the Equator. Because of the precessing rate of the TRMM satellite these crossings occur over a five-day period every 23 days.

2.2 ***Spatial Heterogeneity***

Nadir footprint sizes of ScaRaB FM2 and CERES PFM are about 40 and 10 km, respectively. CERES footprints cannot be averaged (even using a point spread function) over the larger ScaRaB footprints because, in most cases, overlapping CERES and ScaRaB footprints are not viewed with the same angles. However, the discrepancy between CERES and ScaRaB footprint sizes can be reduced by using averaged CERES radiances from several (6-8) adjacent footprints with viewing and azimuth angles no more different than 2 deg. In addition, the two CERES (R_1^{cer} and R_2^{cer}) and two ScaRaB (R_1^{sca} and R_2^{sca}) radiances closest to an intersection are interpolated to the actual orbital crossing location. The difference between the interpolated ScaRaB and CERES radiances (Δ=R^{sca}-R^{cer}) is computed at that location. The spatial heterogeneity of the orbital crossing is determined by computing the standard deviation σ_R of the 4 radiances R_1^{cer}, R_2^{cer}, (R_1^{sca}–Δ) and (R_2^{sca}–Δ). If σ_R is small, it is evidence that Δ is significant. If σ_R is large however, the bias Δ cannot be associated unequivocally with a radiometric difference between the two sensors and the data point is not used. Variability in the scene identification of the four footprints is also an indicator of spatial heterogeneity.

2.3 ***Temporal Variability***

The population used to compare radiances measured by two instruments on two different satellites, is limited to cases when the two satellites pass the orbital crossings within a few (up to 15) minutes of each other. The radiative field can vary significantly within seconds or minutes of one satellite observation, but the level of temporal variability is accounted for in the test using Δ and σ_R.

3. STATISTICAL DATA ANALYSIS

Differences between matched CERES and ScaRaB radiances can originate from several sources: (1) gain and offset used to convert radiometric counts to filtered radiances and (2) assumed spectral responses used to produce unfiltered radiances. Errors in the gain and offset would affect radiances from different scene types equally, while errors in spectral corrections could affect some scenes more than others. Any error in the SW channel would not only apply to SW radiances but also to daytime LW radiances which depend on the good cross-calibration between SW and total channels. Small discrepancies in this cross-calibration were detected for the ERBE sensors onboard the NOAA-9 and NOAA-10 spacecrafts (Thomas et al., 1995). The interpretation of a calibration inconsistency between two radiometers thus needs careful attention and requires a statistically significant population made of independent samples.

It can be argued that the *n* matched ScaRaB and CERES radiances from a single orbital crossing do not constitute independent samples. We define a new variable, $\overline{\Delta}$, the mean ScaRaB-CERES difference for each orbital crossing *j* as $\overline{\Delta}_j = 1/n \, \Sigma_i \, \Delta_{ij}$. Adjacent orbital crossings are separated by about 3000 km so the samples of the variable $\overline{\Delta}$ are assumed to be independent.

To achieve comparisons of CERES and ScaRaB radiances with a high level of statistical significance, we must first determine the required sample size. We use the data available to this date, that is, CERES and ScaRaB observations collected on 17 August 1998. Note that since both instruments were scanning in a cross-track mode, the scanning planes were not aligned and SW radiances could not be matched. The sample size is determined for LW radiances only. On 17 August 1998, TRMM and Resurs-01/N4 crossed each other's path less than 15 minutes apart at 7 different locations around the globe. For each location *j*, a mean ScaRaB-

CERES LW radiance difference $\overline{\Delta}_j$ is computed. The population standard deviation is estimated by the standard deviation σ_Δ of the 7 samples. The required sample size to estimate the mean radiance difference to within 0.25% at the 95% confidence level is given by

$$N = (t_{\alpha/2})^2 \, (\sigma_\Delta)^2 \, / \, (E)^2,$$

where $t_{\alpha/2}$ is the value of the t distribution for a 95% confidence level and 6 degrees of freedom and E is the confidence interval around the mean (we use E=0.25 $Wm^{-2}sr^{-1}$ for LW radiances). With our estimate of the standard deviation, σ_Δ=0.73 $Wm^{-2}sr^{-1}$, the required sample size is N=50 orbital crossings.

In addition to the 7 matched orbital crossings from 17 August 1998, 20 were obtained in January 1999 and 25 in March 1999 most of which with aligned scanning planes. An estimate of the sample size required to reach the desired accuracy for SW radiances will be determined once January 1999 ScaRaB data are available.

4. SUMMARY

Comparisons of contemporary radiance measurements from two independent Earth and clouds radiation monitoring missions is an important contribution to the validation process of these missions. Once the January and March 1999 ScaRaB data are available, we will determine the overall differences between ScaRaB and CERES LW and SW radiances using statistically significant populations of measurements matched temporally and spatially and collected under similar viewing conditions. These results will be presented at the conference. Operation of the CERES instrument with a scanning plane aligned with the cross-track scanning of ScaRaB are scheduled to continue at regular intervals through the first half of 1999.

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